Improving the Bulk Formula for Sea-Surface Fluxes

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LONG-TERM GOAL

Derive a more flexibile form of the bulk forumula for sea-surface fluxes that does not require compliance with Monin-Obukhov similarity theory nor definition of the surface roughness length.

OBJECTIVES

The most important objectives are to generalize the bulk formula to: a) better approximate fluxes for stable weak-wind cases to accommodate the influence of unresolved mesoscale motions, b) account for reduced efficiency of moisture fluxes over cooler water, c) allow for confused seas and weak winds dominated by mesoscale motions through probability distributions of transfer coefficients and d) rexamine the bulk for formula for strong wind conditions. As a parallel investigation, the commonly used TOAGA COARE scheme will be modified.

APPROACH

The bulk formula will be generalized by analyzing several LoneEZ and recent CIRPAS Twin Otter aircraft data sets. Data from the CIRPAS Twin Otter April 08 Pilot Experiment is emphasized in the initial analyses with additional data being added. This analysis is supported by a new QC and analysis package contructed during the first year of the grant.

WORK COMPLETED

During the past year, additional flights from the April 08 Pilot Experiment at Monerey were processed and quality controlled and additional data from the 07 Monterey Experiment were obtained and qaulity controlled. A general study on the variation of drag and transfer coefficients between flights was presented at the AMS air-sea interaction meeting. A more detailed case study was completed on computing fluxes over spatially varying SST and the consequences for the bulk transfer coefficient.

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RESULTS

The past year also incorporated the new Monterey data into an ongoing analysis of the difference between roughness lengths for heat, moisture and momentum. At the writing of this report, the small momentum roughness lengths are being investigated in terms of wind following swell. Nonetheless, the drag coefficient exhibited systematic dependence on the Richardson number.

The main exceptions to this stability dependence are cases of weak winds and small spatially averaged mean air-sea temperature differences due to the impact of modest SST heterogeneity.

The horizontal heterogeneity of the SST is predicted to increase the area-averaged heat flux for weakly unstable conditions, but decreases the area-averaged downward heat flux for weakly stable conditions. For slightly stable area-averaged air-sea temperature difference, variations of the air-sea temperature difference can even lead to ``counter gradient'' upward area-averaged heat flux. A simple analytical development indicates that the influence of variation of the air-sea temperature difference on the area-averaged heat flux is proportional to the square of the SST variability and inversely related to the horizontally-averaged air-sea temperature difference and the square of the wind speed.

The usual methods of computing fluxes are inadequate over heterogeneous surfaces. Inadvertent inclusion of larger mesoscale motions leads to erratic fluxes. Therefore, fluxes were computed from a decomposition into a local (wavelet) basis set where the coefficients of the expansion are allowed to vary with the heterogeneity. This approach not only provides information on the spatial variability of the contribution of different scales to the total flux, but also provides more information for selecting the range of scales included in the flux calculation. This study used the scale dependence of a number of different flow characteristics to assist in determination of the range of scales included in the turbulent flux calculation. With weak turbulence, the erratic mesoscale vertical velocity fluctuations may not be small compared to the turbulent velocity fluctuations, necessitating use of these characteristics.

This case study for small air-sea temperature difference indicates that small variations of the air-sea temperature difference, here on scales of 50 km or less and magnitudes less than 1K, can significantly increase the area-averaged upward surface heat flux beyond the homogenous prediction. As a result of the small surface friction velocity for the case study, small variations of the air-sea temperature difference leads to large variation of z/L. In fact, the transfer coefficient for the area-averaged heat flux is more closely related to the SST variability than the small area-averaged air-sea temperature difference for this data set.

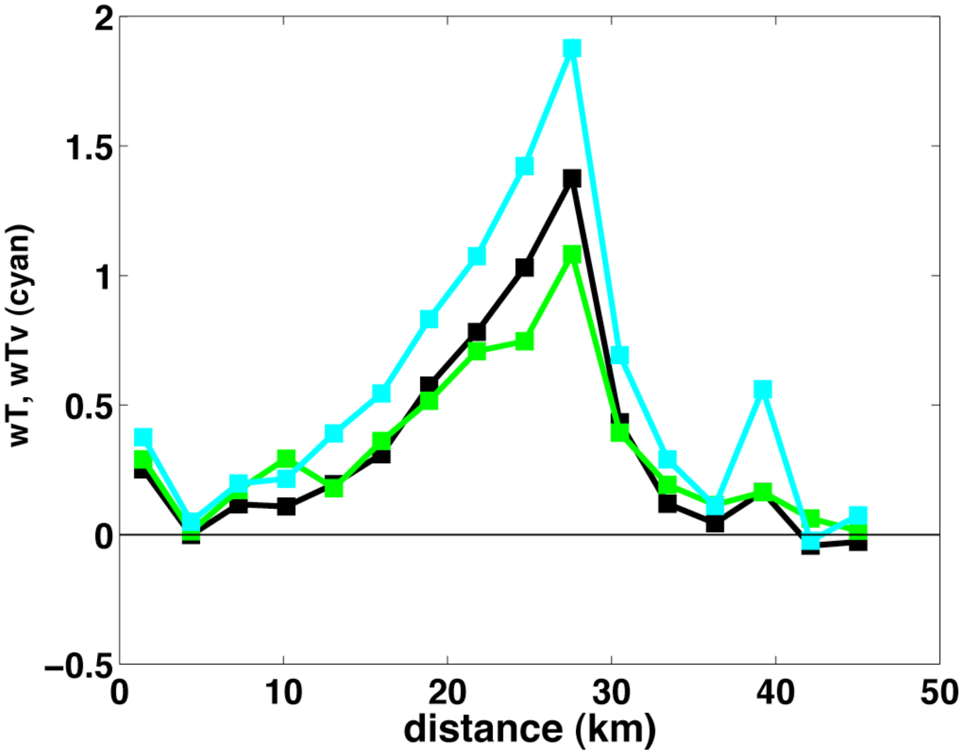

Figure 1. A mini-warm pool of 0.5 K SST excess, centered at about 25 km distance, leads to modest upward heat flux (10^{-3} K m s^{-1}). The heat flux is computed by integrating the multiresolution cospectra over horizontal scales through the 180-m mode (black line). The maximum horizontal scale of 180 m was determined from the new analysis techniques. Also shown are the heat flux values integrated over scales only through the 45-m mode (green line) and the buoyancy flux integrated through the 180-m mode (cyan line). Common use of scales up to1 km or more yields erratic offscale fluxes for this heterogeneous case.

In the coming year, these analyses will be extended to stronger winds in order to form a more general basis suitable for modifying the bulk formula. During the past year, wave state information was included in casual analyses. We are seeking research quality wave data from the Scripps buoy in Monterey Bay to become a part of the analysis. We also plan to incorporate the 2007 Monterey data in the new analysis.

PUBLICATIONS

L. Mahrt and D. Khelif 2009: Heat fluxes over weak SST heterogeneity. Submitted to *J. Geophys. Res.*